

Research Priorities for the International Space Station and Beyond

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Abstract

Advanced technology and the desire to explore space have resulted in increasingly longer manned space missions. Long Duration Space Flights (LDSF) have provided a considerable amount of scientific research on the ability of humans to adapt and function in microgravity environments. In addition, studies conducted in analogous environments, such as winter-over expeditions in Antarctica, have complemented the scientific understanding of human performance in LDSF. These findings indicate long duration missions may take a toll on the individual, both physiologically and psychologically, with potential impacts on performance.

Significant factors in any manned LDSF are habitability, workload and performance. They are interrelated and influence one another, and therefore necessitate an integrated research approach. An integral part of this approach will be identifying and developing tools not only for assessment of habitability, workload, and performance, but also for prediction of these factors as well. In addition, these tools will be used to identify and provide countermeasures to minimize decrements and maximize mission success.

The purpose of this paper is to identify research goals and methods for the International Space Station (ISS) in order to identify critical factors and level of impact on habitability, workload, and performance, and to develop and validate countermeasures. Overall, this approach will provide the groundwork for creating an optimal environment in which to live and work onboard ISS as well as preparing for longer planetary missions.

Research Priorities for the International Space Station and Beyond

Advanced technology and the desire to explore space have resulted in increasingly longer human space missions. International space programs were formed to jointly address and focus on answering questions about human physical and psychological adaptation to long duration isolation in space. Long duration space flights (LDSFs) conducted to date have provided a considerable amount of scientific research on a human's ability to function in extreme environments. This information was complemented by studying environments analogous to those experienced during space travel, such as submarines, winter-over expeditions in Antarctica, and other isolated, confined and/or weightless facilities.

Research findings thus far indicate that the long duration missions may take a toll on the individual, both physiologically and psychologically. Isolated and confined conditions in microgravity environment may result in work performance decrement and reduced group socialization skills (5). These impacts may be magnified with increased mental and/or physical workload. In addition, habitability becomes a critical factor in longer space missions. It may impact the success of the mission by affecting performance, safety and well being of the crewmembers. Thus, interrelations of habitability, performance and workload are crucial factors that need to be investigated through an integrated research approach.

The purpose of this paper is to identify research goals and methods for the International Space Station (ISS). These research goals and methods are needed to:

- (1) identify critical factors and level of impact on habitability, workload, and performance by using existing tools or developing new tools as needed, and
- (2) develop and validate countermeasures.

Theoretical Construct

The most significant human factors elements which are necessary to achieve mission success in long duration space missions are habitability, performance and workload (8). These factors are all impacted by various other conditions such as human-physical environment interface, human capabilities, group characteristics, and operational, mission and environmental factors (See Figure 1). Most of the previous research cited addresses these key areas individually. Since the most limited research has been on habitability, the primary focus of the paper will be habitability and its inter-relations with other factors.

Insert Figure 1 here.

Habitability

Early Habitability Assessments. Early habitability assessments in microgravity environment were conducted through questionnaires completed by Skylab crewmembers. One of the experiments flown on Skylab was Skylab Experiment M487, Habitability/Crew Quarters. This test was used for assessing habitability concerns and equipment in terms of maneuverability and range of

motion. The habitability questionnaires addressed issues ranging from architecture and communication to hardware usability. They were in checklist format with the objective of determining habitability issues onboard Skylab that would benefit designers of future space vehicles (4). One of the major findings of the study was the importance of the habitability provisions (e.g., hardware design) for optimal crew performance. Skylab crewmembers spent half of their waking time on activities such as personal hygiene, eating, and recreation, where habitability provisions had a significant effect on the time required to perform these tasks. The difference between their spaceflight and normal Earth day was the large percentage of time spent on personal hygiene at the expense of recreation and other activities. It was pointed out that slightly more sophisticated equipment or accommodations would have saved crew time.

Shuttle/KC-135 Evaluations. A series of evaluations for Shuttle was conducted in the KC-135 zero-gravity aircraft for a number of crew interface and habitability issues. These topics included evaluating workstations and restraints, neutral microgravity posture, timelining, cable management and stowage, crew and equipment translation, noise, vibration and computer input devices such as touchscreen and voice.

Methodologies used included administration of in-flight questionnaires (either paper and pencil, or electronic), postflight analyses of in-flight video, and postflight debriefs. When required, KC-135 operations were conducted in order to train the crewmembers on the use of flight hardware (e.g., crew restraints) prior to

a mission, or to further investigate the issues identified during the Shuttle missions. For example, physical discomfort experienced during the glovebox operations were investigated further in follow-up KC-135 evaluations to determine the cause of the discomfort and to identify type(s) of restraints that might eliminate this discomfort (7). It was found that the use of glove ports as a restraint was primarily responsible for the discomfort, and that a restraint providing more stability and flexibility helped reduce the discomfort.

These Shuttle/KC-135 evaluations provided an excellent resource to identify and study critical issues in the microgravity environment. They also helped generate guidelines for hardware design and use which were provided to the design engineers.

Mir NASA Assessments. As the American astronauts began living onboard the Russian space station, Mir, for extended periods of time, NASA developed measurement tools to assess some habitability and performance issues such as work and rest hours, and workload. For example, a general questionnaire was developed for use by the Mir crewmembers to help evaluate crew time planning philosophies for ISS. In addition, postflight debriefs were conducted with the American astronauts that lived and worked on Mir. The information from these debriefings about the habitability lessons learned onboard Mir was compiled in a central database. One of the significant findings was the impact of trash management and stowage on habitability and habitable volume. The findings helped initiate the habitability assessment of onboard stowage on planned ISS missions (6).

NASA Habitability Analog Studies. Habitability assessments were conducted during a 60-day and a 90-day mission, the Lunar-Mars Life Support Tests, in a 20-foot chamber. These assessments included administering electronic habitability questionnaires with 5-point scales and open-ended questions, including Space Operations Issues Reporting Tool (SOIRT). SOIRT was developed for describing habitability and performance related incidents during a mission. In addition, post-test debriefs were held with the chamber crews to gather information regarding habitability and interface/usability issues in a confined and isolated environment. Significant findings regarding poor communications, emergency alarms, size of ovens for meal preparations, and surface cleanability provided guidance for defining habitability requirements for long duration missions and human factors design issues (2, 3).

Workload

A lot of research has been conducted on workload and various techniques to measure workload (8). Secondary task and subjective workload assessment tools have been used to determine the level of mental workload and its effects on performance. In general, a correlation exists between high mental workload and performance decrements. As LDSF continues to increase in mission duration and workload, it is reasonable to assume that more stress will be imposed on crewmembers in completing planned tasks. Thus, it is very likely that the frequency of human errors may increase. In addition, “sub-optimal” human-machine interface and “poor” habitability of the environment may have a greater

impact on human error under higher workload conditions. Therefore, more research needs to be done to establish interrelationships between high mental workload and habitability during isolation and confinement on performance decrements.

Mental workload is not the only concern for LDSF. Physical workload must also be considered in relation to performance. Although physical requirements (e.g., torque) may be small, some repetitive tasks may be fatiguing and physically exhausting. In the industrial setting, numerous tools and techniques have been developed for measuring physical workload and performance, including anthropometric and biomechanical assessments and task analysis. However, further studies have to be conducted in order to determine the applicability of these tools and techniques in microgravity environments to identify the need for new tools and techniques and, finally, to compile a database of the microgravity data.

Performance

Various tools and methods have been developed in an attempt to assess in-flight performance (8). These studies have emphasized different aspects of performance such as:

- 1) Psychomotor performance (e.g., tracking and fine manual control)
- 2) Dual-task performance
- 3) Speech analysis to measure emotional state and arousal
- 4) Changes in sleep patterns
- 5) Situational awareness

- 6) Cognitive performance (e.g., logical reasoning, short and long term memory)

The computer-based test batteries used in most of these studies are intended to provide a means for a comprehensive measurement of performance data and to address effects of microgravity in LDSF. In general, results from the research conducted on Shuttle indicated that the performance decrements occurred early in the mission and were found more in tracking and fine manual control. However, the space environment did not impact logical reasoning functions or speed and accuracy of short-term memory retrieval.

Measurement scales and speech analyses were two of the techniques used to determine the effects of mood and motivation on performance. Although promising, more studies on the effectiveness and reliability of this technique are required before they can be used to measure the stress during LDSF.

Recently, much attention has been given to the situational awareness of LDSF crews. It has been reported that LDSF isolation and confinement stressors tend to contribute to situational outcomes that might not otherwise occur. These outcomes may have the potential to degrade performance by the crew. Despite the importance of situational awareness, the most limited research and tool development has been in the field of situational awareness.

Task analysis is the foundation of human-machine interface design. Until recently, most task analyses have focused on the behavioral interactions of the human with the machine, excluding the cognitive aspects of the task (i.e., cognitive

skills needed to perform a task). However, task analysis is now used more to identify the critical and accurate cognitive information in order to enhance the understanding of how the task is performed (1).

Existing Tools and Methods

There have been a variety of tools and techniques developed, tested and used for addressing the issues of habitability, performance and workload (8). These tools have ranged in format from paper and pencil to computer simulation. Many addressed only one of the three critical factors (habitability, performance, and workload) without addressing interrelationships among the three. Most of the tools focused on the assessment of the current state; limited emphasis was given to the prediction of performance in “what-if” scenarios. Forward work is needed to determine their applicability during LDSF, with an emphasis on both the assessment and prediction capabilities of the tools.

Projections for ISS and Beyond

The ISS Assembly has begun. However, there are still opportunities to solve at least some of the habitability issues since the crew has access to the ISS and can modify interior layout configurations during the assembly, in order to prepare the station for permanent on-orbit habitability. Once the crewmembers begin living and working onboard ISS, there will be an opportunity to begin more in-depth assessment of habitability, performance and workload. Thus, it is critical that the plan for the in-flight assessments onboard ISS be initiated immediately and Shuttle/ISS assembly missions utilized as testbeds for testing and verifying the

methods and tools as they apply to ISS. Additional tests and verifications of these tools and methods can be conducted in laboratory and analog environments as appropriate.

The first research priority should be given to the selection or development of in-flight research tools to understand habitability, workload and performance inter-relations in LDSF. The majority of the ground-based tools requires active participation on the part of the human subject and can be time-consuming for in-flight use. Most of them are assessment tools with limited or no focus on “prediction” of potential issues before they happen. Thus, existing ground-based tools should be evaluated for their applicability for LDSF with emphasis both on “self-assessment” and prediction aspects.

Secondly, research priority should focus on general and special-topic investigations in microgravity and analog environments in order to identify the habitability-related critical factors and their level of impact on overall performance. Although the areas of habitability, workload and performance have been investigated considerably, many questions still remain. Despite the depth of knowledge obtained on these topics, only some can be applied directly. In addition, habitability and the interrelationships among habitability, workload and performance have not been studied extensively. General evaluations conducted in-flight or in analog environments will facilitate determining the most critical habitability, workload and performance issues such as the impact of physical interface on situational awareness. Special topic evaluations based on findings

from general assessments can be used as a means to test and verify in-flight assessment tools and prediction, and to determine the effects of microgravity, long term confinement and isolation on the critical factors.

The key to providing “optimal” habitability along with acceptable workload, while maintaining high performance, is using a systematic and integrated approach to conducting human factors research. The implementation of habitability, workload and performance assessments onboard ISS can be viewed as a progression of three stages that should be mapped into the ISS assembly timeline. These stages are: (1) planning, (2) testing and (3) implementation (see Figure 2).

Insert Figure 2 here.

The critical steps for implementation of habitability, workload and performance research include:

- 1) Establish knowledge base of current models and tools
- 2) Determine the need for development of “new” tool(s)
- 3) Test and verify the tools and models
- 4) Identify critical issues/ factors
- 5) Define and test countermeasures to eliminate degradation in critical factors.

Given that there is still a lot to be done in terms of determining the critical factors under the habitability/ workload / performance umbrella, one research

priority for ISS is to promote a better understanding of habitability as it relates to performance and workload. This integrated approach would take advantage of the depth of knowledge in the field of workload and performance and the use of existing tools as appropriate in order to identify critical factors and their level of criticality.

Within this approach, the specific areas of interest are:

1. Human-machine and human-environment interaction

- User interface (both hardware and software)
- Interior layout
- Environmental conditions (e.g., lighting, noise)
- Human capabilities (e.g., how to determine requirements for automation)

2. Assessment of habitability as it relates to performance and workload (e.g., working and living environment, privacy, personal hygiene)

3. Assessment of readiness to perform, and countermeasures to maintain readiness

- In-situ training
- Evolution into “new” crew-ground mission control interaction patterns

Conclusions and Recommendations

Knowing the effects of microgravity, isolation and confinement on habitability, workload and performance would help prevent, if not minimize, the potential negative impacts. With this approach, an environment which was most

conducive to effective performance would be created for the ISS crew to live and work onboard ISS. The lessons learned that would be gained as the assessments are performed would prepare future astronauts for future exploration missions to the Moon and Mars. The best approach to identifying research priorities for ISS and beyond is by establishing a systematic and integrated plan. During ISS Assembly phase, the research priorities are refined by conducting specific and focused human factors assessments, general operational habitability assessments, and verification of pre-determined design requirements to evaluate the validity of their applicability with tests during increased numbers and durations of flights. During Assembly Complete phase, the refined research areas are further investigated via controlled human factors assessments, as well as continuing the general habitability and verification assessment in order to increase the knowledge base. The most important step is capturing the information gained and lessons learned in a well-structured database.

With the assembly of ISS, the next challenge in space human factors is “human engineering” the space systems design so that astronauts from different countries can live and work in space safely, comfortably and with good health, not only onboard ISS but on future planetary habitats as well. Increasing our knowledge base of human factors for extended duration space missions is the critical starting point for the exploration missions. It must be augmented with assessments in analog environments. Based on continued studies, integration of

human factors research and consequent optimal habitability in space will provide new insights into the applicability of human factors research on earth, as well.

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Illustrations

Figure 1. Relationship among key factors affecting mission success.

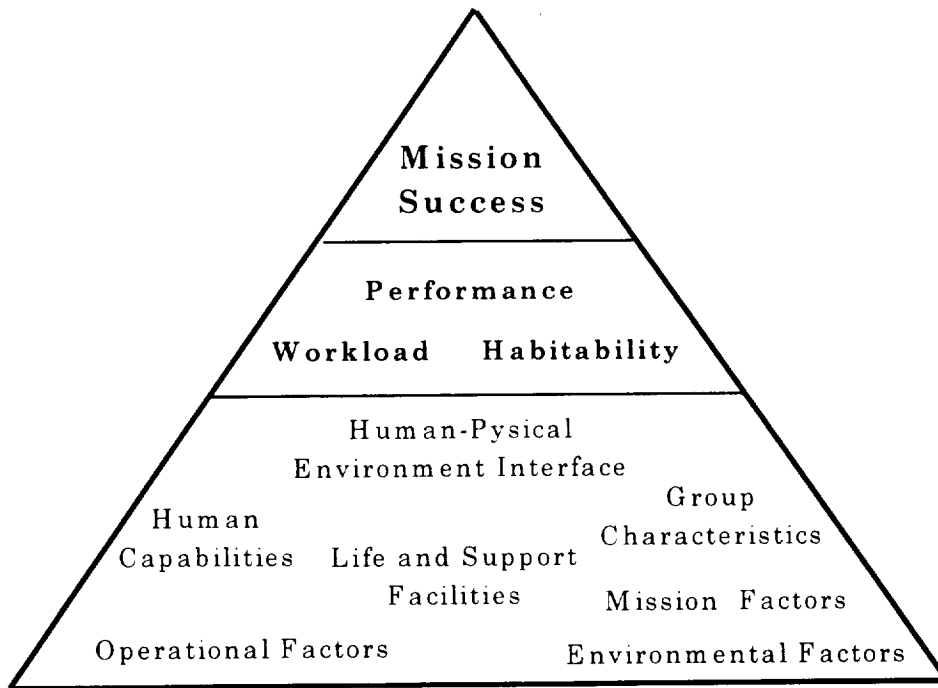


Figure 2. Implementation plan for integrated habitability assessments.

